

ON THE ATLANTIC TROPICAL EXPERIMENT (GATE) SYNOPTIC-SCALE SUBPROGRAM

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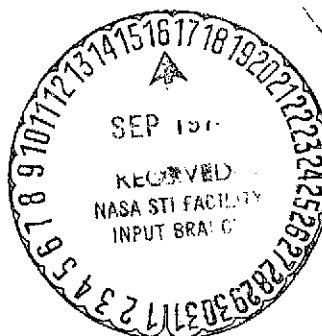
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ON THE SUBPROGRAM OF RESEARCH ON THE PROCESSES OF  
SYNOPTIC SCALE IN THE ATLANTIC TROPICAL EXPERIMENT  
(ATEP)\*

In this article there is an account of the portion /106\*\*  
of the international program for the carrying out of  
Atlantic tropical experimentation in 1974, developed in  
the Soviet Union by a collection of scientists of  
various disciplines, related to researching of the  
processes of synoptic scale in the tropical zone. The  
nature of the intimate relationship between processes  
of various scales in the tropical zone is emphasized,  
indicating the possibility of the existence of wave  
motions of scales of several kilometers arising in  
the meridian flows during the presence of general  
zonal motion in the equatorial belt.

The Soviet program ATEP, developed by a collective of  
researchers of various disciplines, provides for conducting a  
very wide scope of research in the tropical zone of the Atlantic  
Ocean, during the period from July through September of 1974.

For the clearer planning, preparation and execution of the  
ATEP, the whole program was broken down into a series of sub-  
programs. Several of these subprograms will be developed  
together, since the aims, problems, means and materials of  
observations, and even the methods of analysis of the results of  
these observations and measurements in several subprograms have  
common features. As a typical example of interrelated sub-  
programs, one might consider the subprograms of research on the

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\*Atlantic Tropical Experimentation Program

\*\*Numbers in the margin indicate pagination in the foreign  
text.

processes of synoptic scale, the subprograms of research on convections and cloudiness, and the subprograms of research on the surface layer.

The subprogram of research on synoptic scale has come to be termed the central or foundation program of ATEP for a number of reasons. It is concerned both with the development of a numerical model of tropical circulation, with the task of clarifying the mechanism of the interaction between processes in the tropical zone and in the non-tropical zone, and with research on the mechanism of transdistribution of energy by the motion of various scales, etc.

The solution of these problems and related tasks necessitates /107 the focussing of intensive efforts on two basic and large scale problems: improving the accuracy of forecasting weather in general, and finding the necessary and sufficient conditions for the formation of hurricanes and typhoons. According to the deep conviction of the author, the second of these mentioned problems must be the basic heading to all research in progress in the tropics, or, more properly, to all research on tropical weather, especially within the framework of international experiments.

In the process of developing the plans for the ATEP, the subprogram of research on the processes of synoptic scale, both in the international plan and within the limits of the national programs, was associated with resourcefulness and diversity. This appears to be a reflection of a general tendency, characteristic both for "TROPEKS", and for all of "PIGAP". But among the various subprograms of ATEP, the subprogram of research on the processes

of synoptic scale, which Soviet meteorologists intend to carry out in 1974, is more or less clearly directed to the all-encompassing study and clarification of the mechanism of the processes of synoptic scale in the Tropical Atlantic.

Prior to describing the related subprograms, it is necessary to determine what is to be understood under processes of synoptic scales in the tropics, and to mention the basic peculiarities which distinguish the objectives of synoptic scale in the tropics from the objective of synoptic scale in the non-tropical zone.

When people speak of processes of synoptic scales in the non-tropical zone (i.e., scales of 500-2500 km., where one of the basic roles in the dynamics of the processes is played by the horizontal component of the Coriolis force), they usually have in mind a comparison of scales of research (or disturbances) by parallels and meridians, such as is implied by the presence of horizontal isotropes (we will speak of them as "quasi-isotropes", although for a strong stylist this term may also serve as a form of vulgarism). In the middle belt of  $\pm 30^\circ$  of the related quasi-isotropes, it is only possible to speak of it in isolated instances.

About the horizontal "anisotropism" of the processes, one must understand these processes both from the standpoint of consideration of discoveries derived from the observational data of various types of disturbances, and by the development of a program of similar observations and the analysis of the results of these observations.

The analysis of separate known synoptic observations at the end of the sixties and the beginning of the seventies made it possible to "feel" the force process in the pole of the wind

during a period of 4-5 days (manifesting itself with greater legibility in the lower troposphere) and over a period of 10-15 days with a maximum amplitude close to the level of 200 millibars. The nature of these waves is unclear, and there exists controversy among existing hypotheses. The more or less reasonable hypotheses are based upon the analysis of the energy cycle of the waves. The kinetic energy may "be injected" to the wave due to the horizontal volume along the meridian.

$$\left( -\frac{\partial}{\partial y} (\Phi' v') > 0 \right)$$

or in consequence of the appearance of barotropic instability

$$\left( -\frac{\partial u}{\partial y} u' v' > 0 \right)$$

or due to the transformation of the accessible vortex potential energy

$$\left( -\frac{\partial}{\partial t} \frac{d\Phi'}{dt} > 0 \right)$$

(t-time, axial y-direction from the equator, u, v-components of speeds of the wind along parallels and meridians  $\Phi$ -geopotential, a-parameter of static stability; the horizontal strokes indicate deviation from the mean, designated in the formulas.)

Anisotropy manifests itself, basically, in the increase of scales of objects in the latitudinal direction, in comparison with the meridian direction; the latter will decrease approximately to 50-100 km. Quasi-two-year shifts of the zonal winds in the lower stratosphere and VZK may serve as experimental examples.

The first example--this is a large component of the general circulation mechanism, the completion of whose parts may serve as

indicators of ongoing processes in other wide areas, and consequently, may be directly utilized for long term forecasting. [3] The second example, VZK, is the formation of synoptic scale stretched out in the latitudinal range and "narrow" in the meridian; it most frequently manifests itself in relief in the clustered ensembles, i.e., in the processes, the dimensions of which are assumed to relate to the intermeteorological scales. For this reason it is impossible to construct sharp borders between the processes of scales A and B\* in the tropical zone; this is why, in particular, one of the nodal tasks of ATEP-74 appears to be research on the relationship of scales A and B.

Speaking of wave disturbances in the tropics, it is impossible to ignore the so-called equatorial waves which have not even been assigned theories in suppositions, the physical sense of which is not always easy to accept. For example, equatorial waves of the Kelvin type, resulting in the hypothesis of vertical speed that is principally inadmissible for the narrow,  $\pm 5^\circ$  equatorial band. In this sense, general barotropics, for instance "quasihorizontals", are in my opinion generally inapplicable to modelling processes in the tropical zone. /108

Of a similar nature, wave motion may be discovered in the tropical belt, including the narrow equatorial zone. A national program of ATEP, developed in the United States, will provide for carrying out observations, and analysis of the results of observations, directed towards the discovery of waves of the

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\*We understand that in the Joint Organizational Committee of terminology, Scale A corresponds to synoptic scales, B to meso-meteorological, C to the scale of separate clouds and small systems and D, to very small formations, the dimensions of which are smaller than 1 km.

Kuo-Yanai type, with nonsymmetry of distribution to the east and the west.

Regarding the equatorial zone, the theoretical constructions here are very complicated, and present observations are very sparse, both in quantity and quality of relationships. The method of research of complex processes by means of expansion to elementary waves is very easy and generally accepted, but for some reason it "works" with difficulty during research of processes in the equatorial belt; members interfere with the vertical component of the force of Coriolis.\* Research in past years has shown that rejection of members in calculations of movement may lead to a false disturbance, for example, of computers. For a long time it seemed that a well-founded wave solution for the equatorial belt simply didn't exist. However, a wave solution could be found for a simple clear model encompassing the meridian transfer during conditions of general zonal flow. Namely, if in calculations of motion, written for the equatorial zone, it is assumed  $\frac{\partial}{\partial x} \equiv 0$  (axis x--along the equator to the east), then [2] the following system of equations may be properly derived.

$$\frac{d}{dt} \left( u - \frac{\omega y^2}{r_0} + 2 \omega z \right) = 0,$$

$$\frac{d}{dt} \Omega_x = -2 \omega \left( \frac{\partial u}{\partial y} + \frac{y}{r_0} \frac{\partial u}{\partial x} \right) + \frac{g}{T} \left( \frac{\partial T}{\partial y} - \frac{\gamma}{g \rho} \frac{\partial p}{\partial y} \right).$$

In this case

$$\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0.$$

$$\frac{d}{dt} \equiv \frac{\partial}{\partial t} + v \frac{\partial}{\partial y} + w \frac{\partial}{\partial z}; \quad \Omega_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}.$$

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\*Even in those deep and comprehensive investigations on wave pressures in the atmosphere, as in the monograph of L.A. Dikiy [1], there is employed the "traditional rejection of partials with W."

(In addition to the earlier directions here completed, the following symbols are used:  $\omega = 7.29 \cdot 10^{-5} \frac{1}{s}$  -- directional speed of rotation of the earth;  $r_0 = 6.27 \cdot 10^6$  m -- average radius of the earth;  $\omega_z$  -- vertical component of speed at the axis  $z$ ;  $g$  -- velocity of the force of gravity;  $\rho$  -- density;  $p$  -- pressure;  $T$  -- temperature;  $\gamma$  -- vertical temperature gradient;  $\Omega_x$  -- projection to the axis  $X$  of vortex of speed).

For the simple model (Dobryshman, E.M. Research on the characteristics of motion of the atmosphere in the lower latitudes - Work of the All-Soviet conference on general circulation of the atmosphere. "Nauka", 1972) it is possible to assume

$$u - \frac{\omega y^2}{r_0} + 2 \omega z = u_0 = \text{const.} \quad (1)$$

We proceed further

$$\left| \frac{\gamma}{g \rho} \frac{\partial p}{\partial y} \right| < \left| \frac{\partial T}{\partial y} \right|$$

which is completely natural, since the original equations will not describe the adaptation of the poles of pressure and wind; disturbances in the pole of the wind are calculated, for the most part, by disturbances in the pole of temperature.

Interpolating the function of flow in the plane  $(y, z)$  from the relationship

$$v = - \frac{\partial \psi}{\partial z}, \quad w = \frac{\partial \psi}{\partial y}$$

We transfer the equation for  $\Omega_x$  in the manner

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$$\frac{\partial \Delta \psi}{\partial t} + (\psi, \Delta \psi) = \frac{g}{T} \frac{\partial T}{\partial y}$$

(2)

(In the denominator set  $\bar{T}$ , inasmuch as for the troposphere it is possible to consider  $\frac{g}{T}$  as a parameter, weakly changing with altitude). Together with the equation for the inflow of heat, by the record in the adiabatic proximity.

$$\frac{\partial T}{\partial t} - \frac{\partial \psi}{\partial z} \frac{\partial T}{\partial y} + \frac{\partial \psi}{\partial y} \left( \gamma_a + \frac{dT}{dz} \right) = 0 \quad (3)$$

( $\gamma$  - dry adiabatic vertical temperature gradient) we derive a system of equations, one of the solutions of which will be the function:

$$\left. \begin{aligned} T &= T_0 - \gamma z + T_1 e^{i(my + nz - \sigma t)} \\ \psi &= \psi_0 - Vz + \psi_1 e^{i(my + nz - \sigma t)} \end{aligned} \right\} \quad (4)$$

During which the phased speeds and amplitudes of waves are calculated with the correlations:

$$\sigma_{1,2} = m \sigma_{1,2}^0 = m \left[ V \pm \sqrt{\frac{g(\gamma_a - \gamma)}{T(m^2 + n^2)}} \right] \quad (5)$$

$$\psi_1 = \pm T_1 \sqrt{\frac{g}{T(\gamma_a - \gamma)(m^2 + n^2)}} \quad (6)$$

For the measure

$$\sqrt{\frac{g(\gamma_a - \gamma)}{T(m^2 + n^2)}}$$

there is a Brent Biasal periodicity.

We return our attention to several analogous formulae (5) with the classic formula for waves of Rossby-Gaurvits-Blinova

$$\sigma' = m_1 \left[ U - \frac{\beta}{m_1^2 + n_1^2} \right] \quad (5')$$

where  $M_1$ -wave quantity ("along" the basic zonal flow (or current));

$n_1$ -wave quantity by the second coordinate-meridian;  
 $\beta$ -parameter of Rossby.

From the formula (5) it is obvious that the phased speed of a wave is also proportional to the wave quantity along the basic meridian motion which is already present. Moreover, the smaller the dimension of the wave, then the smaller is the readjustment to the speed of the basic current. The readjustments are various, but for the very small waves they are completely insignificant, so that in both these incidences small waves seem to be "carried away" by the basic current. In both instances stationary, or more properly "quasi-stationary" waves may exist when ( $\delta \approx 0$ .)

Assuming for simplicity of calculation by a symmetrical that the disturbance ( $m=n=\frac{2\pi}{L}$ , where  $L$ =wavelength) we find when  $\bar{T}=300$  K,  $\gamma_a - \gamma = 3.10^{-3}$  °C/m,  $g=9.8$  m/s<sup>2</sup>, that the dimension of the quasi-stationary wave  $L$  will be calculated by the formula

$$L = 10^3 V \quad (V \text{ in m/sec, } L \text{ in m})$$

under the conditions of a meridian current  $V=2$  m/s,  $L \approx 2$  km.

A second wave must also simultaneously exist, shifting by current with doubled speed.

By this very important moment the fact appears, that the amplitude of the wave in the pole of the wind is proportional not only to the amplitude of the temperature of the wave, but that it is practically proportional even to the dimension of the temperature of the wave. Actually, having reckoned for the simplification of the calculation, again  $m=n=\frac{2\pi}{L}$  and we transfer the formula (6) in the form of

$$\psi_1 = \pm \frac{T_1 L}{2\pi} \times \sqrt{\frac{g}{2 \bar{T} (\gamma_a - \gamma)}}$$

This simple model that we have considered creates the possibility of very roughly and qualitatively describing the instability of wave disturbances as well. Namely, the equations of the model in several approximations hold true also for the emergence of condensation; it is necessary to substitute only  $\gamma_a$  for  $\gamma_{sa}$ , the saturated adiabatic vertical temperature gradient. In this instance, i.e. during condensation, the stability of the wave may be disturbed by the condition  $\gamma_{sa} - \gamma' < 0$ . Such a relationship may be observed in various zones along the longitude and in several ways may explain the mechanism generating clouds of the penetrating convection type. /110

We recall that the described wave processes of the scale C originate in the general background of the zonal transfer (calculated by the theorem of the constancy of the slope moment (1)), which naturally refers to the process of scales A or A-B for the equatorial zone.

Since the accuracy of the implementation  $\frac{\partial v}{\partial t} \approx 0$  is approximately the same as  $\frac{1}{\partial x} \frac{\partial p}{\partial x} \approx 0$ , and is approximately 500-700 km., and since the equatorial belt on every side of the equator has the same dimension, then naturally the organization suggests some special polygonal measures in the scale B (and even better in the scale B-C) in the 0-5° belt. Therefore it is proposed that observations be carried out in the polygon 0-5° in one of the gaps of observation in the scale A and A-B by means of several (in the authors' opinion five) ships over a period of three days. This will create the possibility of answering and clarifying a series of questions on the characteristics of processes in the equatorial belt and of their relationship to processes in the tropical belt. In this way, several accents on research of wave processes in the equatorial belt provided for by the Soviet program of work in

ATEP, and the accent on research of wave processes of greater scale provided for by the program of the U.S.A., will permit a substantially closer examination of our notions about the mechanical processes taking place in the tropical zones.

We have considered in depth one aspect of the subprogram of research on processes of synoptic scale, in order to demonstrate the complexity and variety of the problem; on the one hand, to emphasize several new phases in the subprogram, on the other, and finally, to give the most accurate concept of how to proceed with the development of a detailed plan for every section of the subprogram in its entirety.

Proceeding from an analysis of the possibility of conducting ATEP, and the determination of a collection of most important tasks, the whole program of research of processes of synoptic scale developed by Soviet scientists, is broken into three sections:

#### I. Numerical modeling of processes in the tropical zone

Basic attention will be directed toward the following tasks:

1. The improvement of existing hemispheric and global models of the general circulation and of mathematical forecasting. In this aspect it is the development of new as well as existing mathematical models planned with the purpose of the expansion of these models into the area of ATEP, and with the purpose of determining processes in the tropical zone in the general circulation of the atmosphere, and also for the prediction of the pole of meteorological elements.

2. The improvement of mathematical schematics for circulation and forecasting in the tropics. In this aspect it is proposed that the adiabatic model be used for short-term forecast in the organized territory, and that experiments be carried out on the parametrization of nondiabatic factors with the application of Newton's Law. In the adjacent latitudes it is proposed that the term of the "wall" be used. Incidentally, in the area B there may be considered a series of characteristics necessary to the analysis of processes in the given zone (differential, vortex, vertical speed, gradients of basic meteorological elements, component equations of motion, continuity and flow of heat.)
3. Research on the dynamic of processes of the scale B in the narrow belt  $0-5^{\circ}$  s.sh. For the elucidation of mechanisms of exchange with masses between the hemispheres, the interaction of processes of the scales A and B in the tropical zone, transfers and transdistributions of energy along the scales of motions in the tropical zone, it is necessary to carry out detailed research of processes, occurring in the narrow equatorial belt, where the hypothesis of quasihorizontalness of motions determined by the influence of the horizontal component of the force of Coriolis is irrelevant.
4. The development of schemes of objective analysis of poles /111 of basic meteorological elements in the zone of the carrying out of ATEP. Existing schemes of objective analysis of the poles of basic meteorological elements will be adopted to the ATEP zone by means of "assimilation" of data of the northern and southern hemispheres simultaneously, determination of shifting points of

observation, determination of the information with an artificial earth satellite, and refinement of the analysis of the aerological information by means of enlisting land data and others.

## II. Analysis of Processes by Synoptic Methods

Here research on the following group of questions is provided for.

1. Wave motions of VZK discovered in the past during TROPEKS-72. The calculation provides for characteristics of wave motions (amplitude, period, phase) and the clarification of conditions of emergence of wave processes, and likewise the construction of modelled poles of divergence, vortex and vertical speed.
2. Research on conditions of aggravation and of discontinuities of VZK. Plans have been outlined to clarify the structure of VZK, and likewise the reasons for aggravations of VZK; to set up with poles of divergence in the scales A and B, it is proposed that findings be verified which were made during TROPEKS-72 of the relationship between activity of the convection process and the magnitude of divergence in periods of aggravation and discontinuities of VSK; and also to derive more complete statistical material, verifying the relationship of time scales of evolution of VZK and subtropical anticyclones.
3. Research on trade winds. a/Research on the inversion layers. b/Research on the relationship of eastern circulation and subtropical jet streams.

It is proposed that the role of subtropical jet streams in the formation of trade inversions be clarified.

4. Research on the conditions of emergence and development of tropical depressions. It is proposed: a/to verify the formation in TROPEKS-72 of the hypothesis of large scale diversion in the upper layers of the troposphere as a reason for the formation of tropical depressions and the activation of convection in VZK. b/to research the evolution of aerological poles during the emergence and shifting of tropical depressions.
5. Research on the structure of zonal flow and temperature in the area of motion of the equatorial quasi-two-year cycle. It is proposed: a/ to research characteristics of the interaction of quasi-two-year cyclicity of summer and winter hemispheres. b/ to research the connection between the position of the maximum of zonal currents of a quasi-two-year cycle and VZK.

### III. Statistical Methods of the Analysis of Processes

This section is divided into two main tasks.

1. The determination of wave agitations (disturbances) in the area of ATEP. It is proposed to use spectral methods of developing data of aerological and meteorological observations during the time of the carrying out of ATEP. Basic attention will be paid to the interval frequencies satisfied by a period of 3-5 days.

2. Research on the interrelation of atmospheric processes of various scales with statistical methods.

The basic task of research is the development of methods of parametrizing processes of lesser scales around the characteristics of processes of greater scale. Additionally, there is the problem of predicting appearances of individual objects with the help of analogs and statistical methods.

In closing, it is necessary to say that both the whole subprogram in general and the innumerable fundamental tasks are connected with other subprograms both in the framework of international subprograms for research in the tropical zone during ATEP-74.

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